Nonlinear parametric resonances in aperiodic dispersion oscillating fibers

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The modulation instability (MI) of a continuous wave background has been widely investigated in various fields of physics. In nonlinear fiber optics, the longitudinal and periodic modulation of the fiber dispersion may lead to a quasi-phase-matching (QPM)-induced MI process with the emergence of well-separated, and unequally spaced gain sidebands, symmetrically placed around the pump [1,2]. In this context, one may wonder how deviations from a strictly periodic evolution of the fiber parameters may affect the QPM-MI spectrum.

To answer this important question, we numerically study the impact of a linear longitudinal evolution of the main parameters of a highly nonlinear dispersion oscillating fiber with normal average dispersion at telecommunication wavelengths [3]. By using systematic simulations of the nonlinear Schrodinger equation (NLSE) and an approximate approach that is based on the Floquet theorem and the associated linear stability analysis, we separately analyze the influence of each parameter of the dispersion-oscillating fiber (DOF), i.e., the dispersion oscillation spatial period, the value of the average dispersion, and finally the amplitude β_{2amp} of the dispersion oscillations. According to the parameter under study, different behaviors are observed, such as a dramatic drop of the maximum gain value, the splitting and fan-out of the resonant sideband frequencies or the emergence of an oscillatory pattern in the sideband spectrum. We also found that, with a linear variation of the spatial period, the output spectrum may depend on the direction of propagation along the chirped DOF.

As an illustration of some of the new features that may appear in a DOF with a linearly increasing or decreasing parameter, we have summarized in Fig. 1(a) the impact of the relative variation of β_{2amp} on the output spectrum. In this configuration, since the central frequency of the parametric resonance sidebands does not depend on β_{2amp}, the gain of the first QPM sideband is only moderately affected by the longitudinal changes of β_{2amp}. However, for some higher-order gain sidebands (in the present case, the 4th order QPM sideband), the gain can be increased by more than 20 dB, which can be reproduced by an approximate LSA-based approach (see Fig. 1c). Another remarkable feature shown in Fig. 1(b) is a novel mechanism for the splitting of the resonance sideband spectrum, which is analogous to the Zeeman splitting of the spectral lines in a gas in the presence of a strong magnetic field, owing to the two states of the spin of the electron [4].

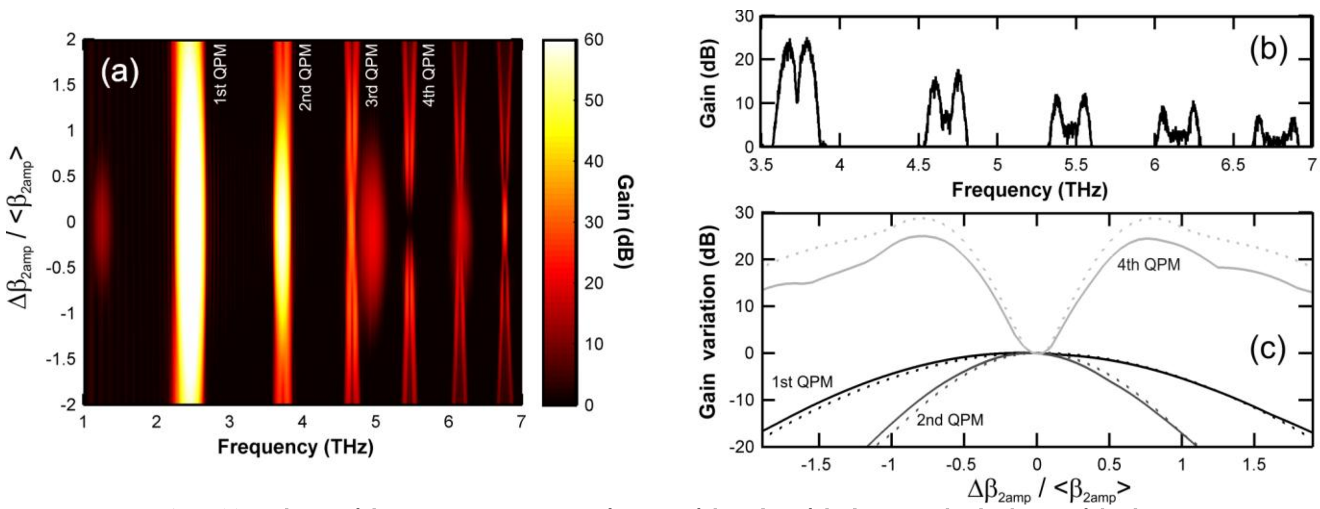

Fig. 1 **(a)** Evolution of the MI gain spectrum as a function of the value of the linear amplitude change of the dispersion fluctuations. Results are obtained from the numerical integration of the NLSE. **(b)** Details of the output spectrum recorded for $\Delta\beta_{2amp}/<\beta_{2amp}>=2$. (c) Evolution of the maximum value of the sideband gain vs. $\Delta\beta_{2amp}/<\beta_{2amp}>$ for various sidebands (black, dark grey and light grey are for the first, second and fourth QPM sideband, respectively). Results from the numerical integration of the NLSE (solid curves) are compared with predictions from LSA (dotted curve).

References

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978-1-4673-7475-0/15/$31.00 ©2015 IEEE